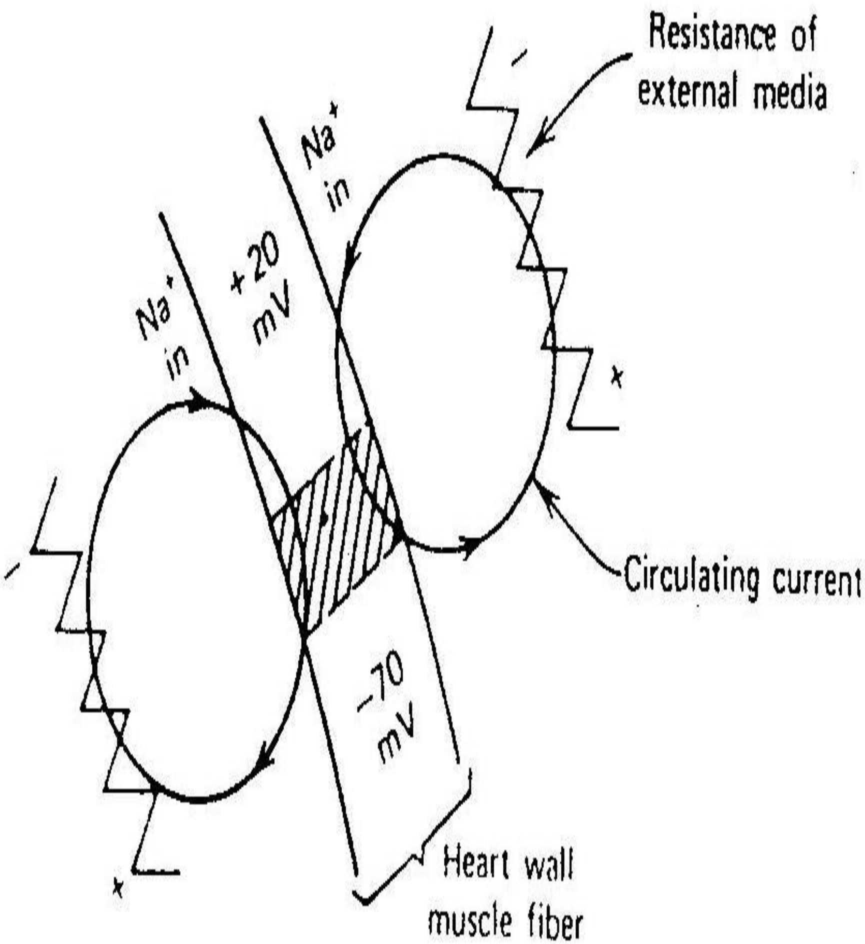
Cardiovascular Instrumentation

1.BIOTENTIALS OF THE HEART

Movements of ions into muscle fibers (cells) of the heart cause action potentials, which produce the contraction. Ion movements in heart muscle cells constitute a current flow, which results in potential differences in the tissue outside the fibers and on the surface of the body (Fig. 1).



This current only flows while the action potential is propagating (mainly during the QRS wave of the ECG) or during the recovery period (T wave). At the peak of the R wave, the potentials on the surface of the body are as shown in Fig. 2

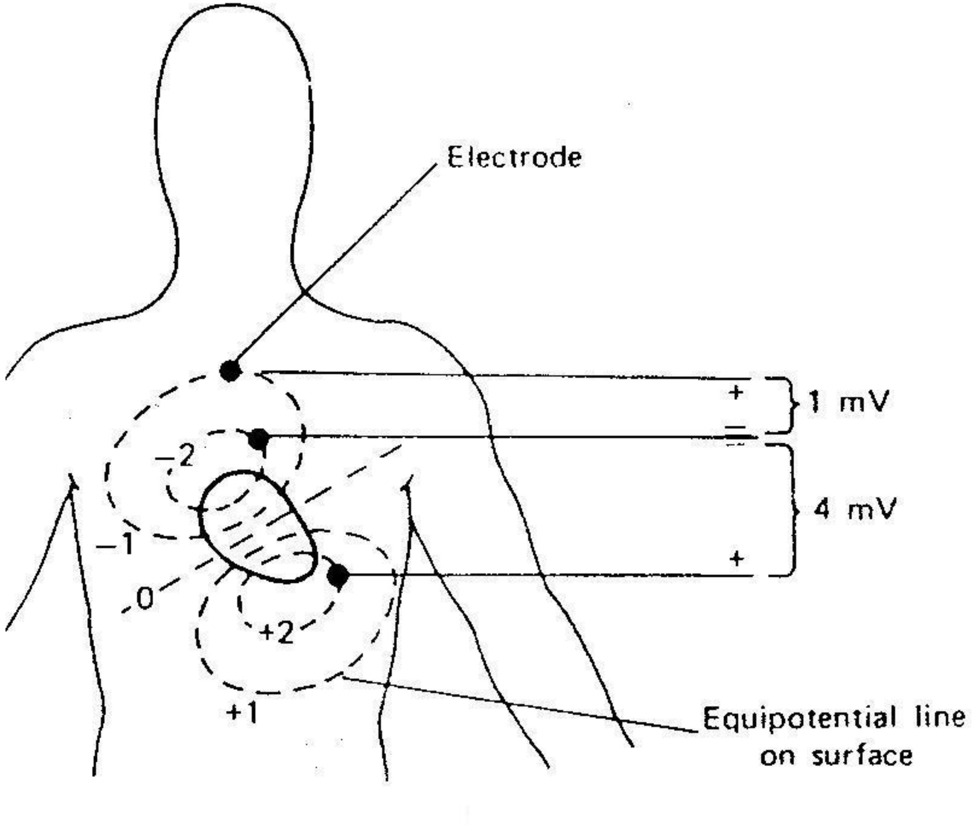


Fig.2. The dashed lines show the resulting surface potentials. The difference in the measured potentials caused by using different electrode locations. Both voltage and polarity my change with electrode position

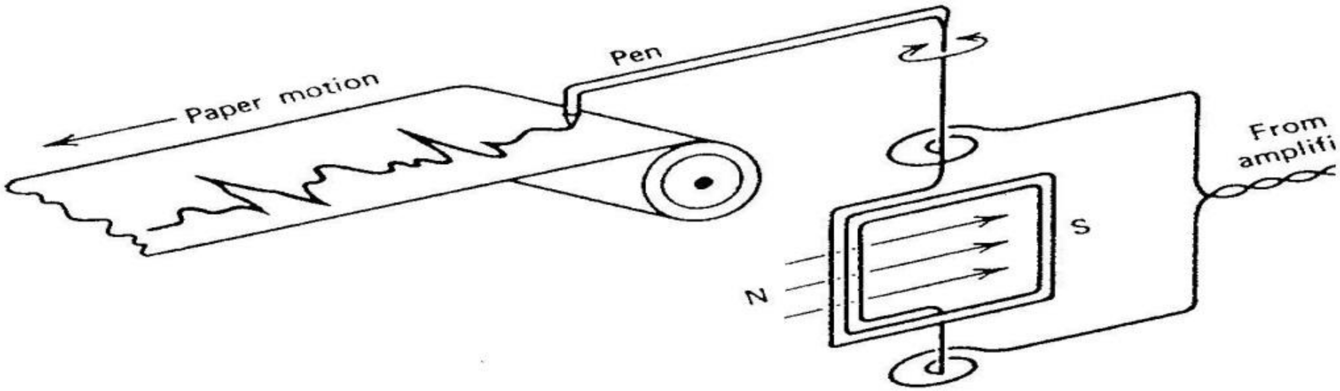
2.ELECTRODES

At the interface between the body and a mental, ion flow must be converted to electron flow through a chemical reaction.

3.AMPLIFIERS

The amplitude of the typical ECG signal is only about 1 mV . However, in a typical building the current capacitively coupled into the body from the 120 V power lines can produce a much larger potential. The amplifier used to record the ECG must be able to eliminate interference from voltages induced in the body from such external sources.

4. PATIENT MONITORING

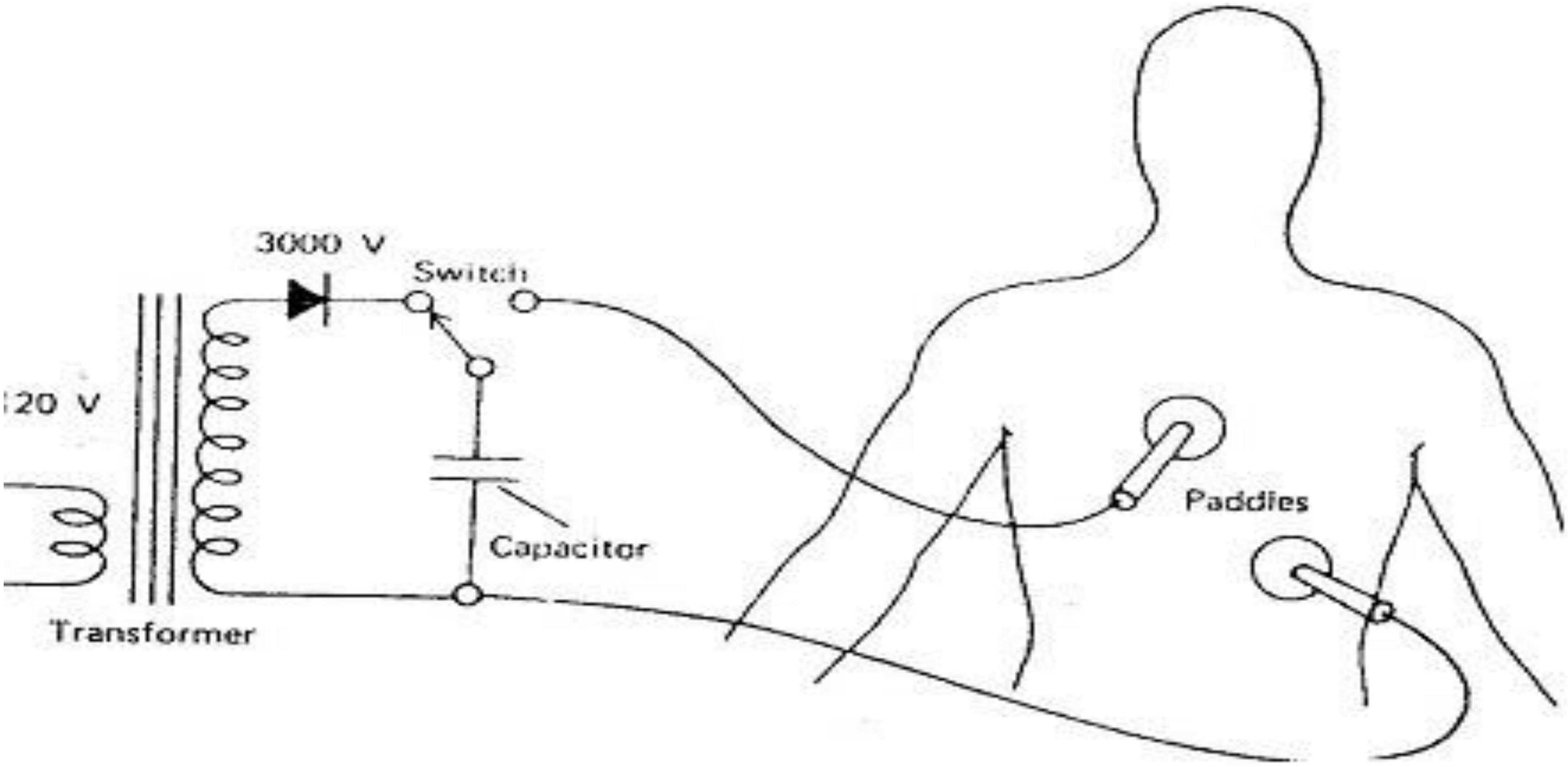


After amplification, the ECG signal must be displayed. When a routine diagnostic ECG is taken, a permanent record is required for analysis and a pen recorder is usually used (Fig.3). In a pen recorder, the amplifier output passes through a coil of wire suspended in a magnetic field. In the same way that a galvanometer twists when current passes through it, the pen twists to write on a moving strip of paper.

5.DEFIBRILLATORS

The reason for continuously monitoring the ECG is that problems arise, prompt therapeutic action can be taken to save the patient's life. Many heart attack patients undergo sudden changes in rhythm. The orderly heart muscle contractions associated with normal heart pumping change to the uncoordinated twitching of ventricular fibrillation, which halts the heart pumping action. Death follows within minutes unless the heart can be defibrillated.

Defibrillation is accomplished as shown in Fig. 4. The paddles are mental electrodes 7.5 cm in diameter that are coated with conductive paste and placed above and below the heart. The paddle handles are made of plastic and are electrically insulated to prevent accident shock to the operation. When the switch is thrown, a current of about 20 A flows through the heart for about 5 mill second. This current contracts every muscle fiber in the heart at the same time. All muscle fibers then recover at about the same time, and the heart can initiate normal rhythm again.

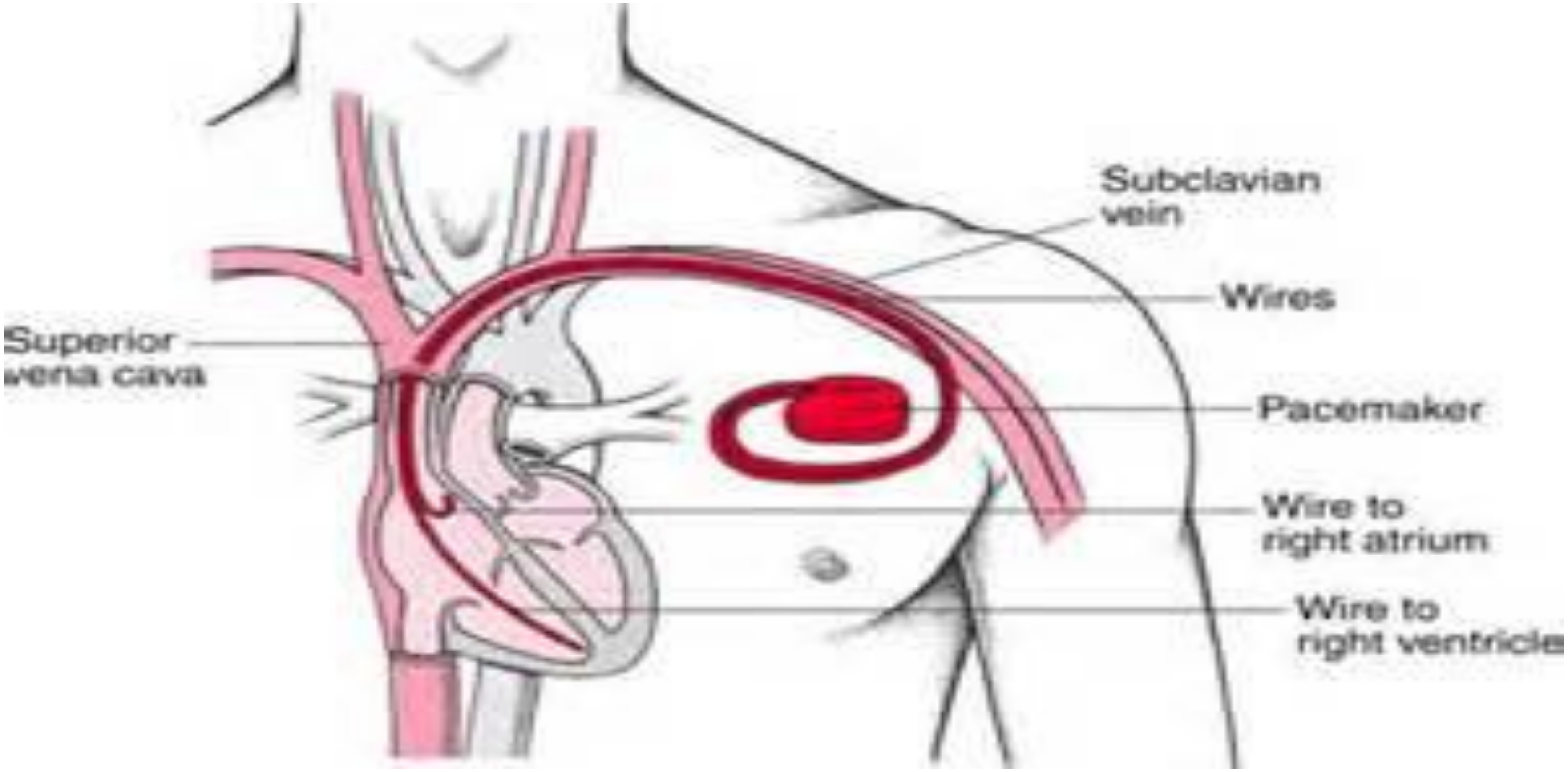


(Fig. 4). A simple defibrillator. The line voltage is stepped up to several thousand volts by a transformer. A diode rectifies the alternating current into direct current to charge up the capacitor. When the switch is thrown. The capacitor discharge through the paddles and the heart.

6. PACEMAKERS

The atria of the heart are separated from the ventricles by a fatty layer that does not conduct electricity or propagate nerve impulses. At a single location, the atrioventricular node, impulses from the atria are conducted to the ventricles, which perform the heart's pumping action. If this node is damaged, the ventricles receive no signals from the atria. However, the ventricles do not stop pumping; there are natural pacing centers in the ventricle a pulse if none has been received from the atria for 2 seconds. The resulting heart rate, 30 beats/min, will sustain life, but the patient may have to live a life of semi-invalidism.

To improve the quality of life for patients with faulty atrioventricular nodes, artificial pacemakers have been developed. The pacemaker contains a pulse generator that puts out 72 pulses/min. The pacing wire is fed through a slit in the shoulder vein and advanced under fluoroscopic control until the tip is imbedded in the wall of the right ventricle (Fig. 5).



- **(Fig.5). Pacemakers provide electrical pulses to the heart in order to produce a normal heart rate.**

Applications of Electricity and Magnetism in Medicine

1. ELECTRICAL SHOCK

When an electrode is connected to each hand and 60 Hz currents of different levels are passed through the body. The amount of current depends on the resistance of body between two points due to Ohms law

$$V = I \times R$$

As the current is increased from zero, the level at which we can just feel the current- the perception level is reached. About 50% of adult men fell a 60 Hz current of about 1 mA. For women about one third lower than those fell. The perception level is frequency dependent; it rise as the frequency increases above 100 Hz.

As a 60 Hz current is increased above the perception level it causes a tingling sensation in the hands.

1. At current of 10 to 20 mA.

A sustained muscular contraction takes place in hands and many subjects cannot let go of the electrodes. (Note that this current is higher at both low and high frequency) in (Fig. 6). As the current increased still further, pain and some cases fainting occur.

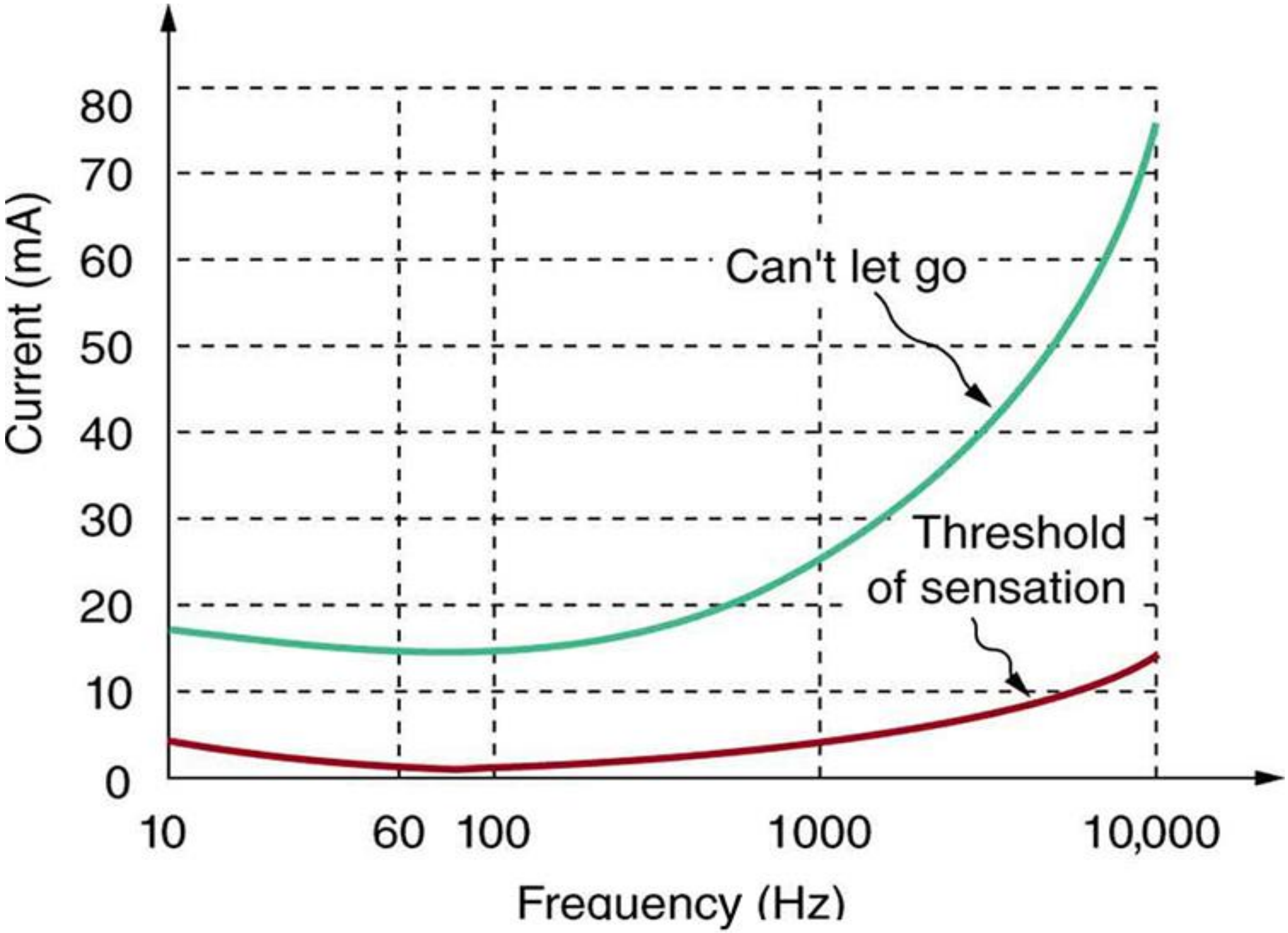
2. Near the 100 mA level the portion of the 60 Hz current passing through the heart is sufficient to cause ventricular fibrillation. (rapid, irregular, and ineffectual contraction of the ventricles).

3. For a 60 Hz shock, the estimated maximum current that will not induce fibrillation in man is given by ($116/t^{1/2}$) mA, where t is the time (in seconds) the shock tests.

For example: if $t = 1$ s the safe current is 116 mA

If $t = 4$ s the safe current is 58 mA

4. Current levels of 6 A and above cause sustained muscular contraction of the heart similar to the (cannot let go) behavior of the hands. Defibrillators make use of such current levels. If a potential has ventricular defibrillation, a brief shock from a defibrillator usually restores normal coordinated pumping in the heart. The defibrillator uses a brief pulse of up to 10 Kv. A defibrillator can also be used to synchronize the heart to its normal rhythm when a patient has atrial fibrillation, in this case the electrical pulse is applied after R wave but before T wave .


Current (mA)
80
70
60
50
40
30
20
10
0
10
60
100
1000
10,000
Frequency (Hz)
Can't let go
Threshold of sensation

5. Continuous currents above 6 A can cause temporary respiratory paralysis and serious burns. The damage depends upon the individual, the dampness of the skin, and the contact of the skin with the conductor.

MACROSHOCK

Which occurs when electrical contact is made on the surface of the body.

MICROSHOCK

When the current is applied inside the body, microshock results. In microshock, the current does not have to pass through the high resistance of the skin; it instead often follows the arteries and passes directly through the heart. Ventricular fibrillation can be induced with microshock current levels that are much smaller than the current levels needed to induce it under macroshock conditions. It has been estimated that about 30 µA cause ventricle fibrillation.

It is possible for microshock to occur in a medical situation, hazards of this sort are correct by modern power cords have three wires-two that supply the ac power and one that serves as ground wire. If either of power wires breaks the equipment will not operate, and if these wires touch (short) a fuse will blow and the failure will be obvious. A break in the ground wire may go undetected and present a serious electrical hazard to patient internal electrodes, some current flow from the ac power parts to the metal case of the instrument is called Leakage current, usually flows to ground through ground wire in the power cord. The main source of the Leakage current is capacitance between the power wires and ground or between power transformer and its case.

The impedance $\mathbf{X_c}$ of a capacitance **C** for applied voltage frequency **f** is

$$\mathbf{X_c = 1/\ 2\,\pi\ f\ c}$$

A typical Leakage capacitance is **2×10^{-2}µf.** If the ac potential **V** is **110 v** at a frequency of **60 Hz,** then the capacitive reactance is **$1.3 \times 10^{5}\Omega$** and Leakage current

$$\mathbf{I = V / X_c = 110 / 1.3 \times 10^{5} = 8.5 \times 10^{-4}\ A = 850\ \mu A}$$

Let us consider what would happen if this Leakage current were in a ECG instrument with broken ground wire and the unit were connected to a patient in an intensive care units who also had a pacemaker connected. Since the Leakage current could not flow to ground through the broken ground wire it would flow through the implanted cardiac pacemaker to ground.

microshock current could result in ventricular fibrillation and death.

There are a number of ways that shock hazards could be reduced.

1- The body is less sensitive to direct current than to 60 Hz current.

Since $\mathbf{X_c = \infty}$ **if** $\mathbf{f = 0}$

There would be no Leakage current due to stray capacitance if we operated our electrical equipment with direct current.

2- Hazards could also reduce at frequencies much higher than 60 Hz where the sensitivity of the heart to ventricular fibrillation is much less.

HIGH-FREQUENCY ELECTRICITY IN MEDINCINE

The heating effects produced by electrical diathermy.

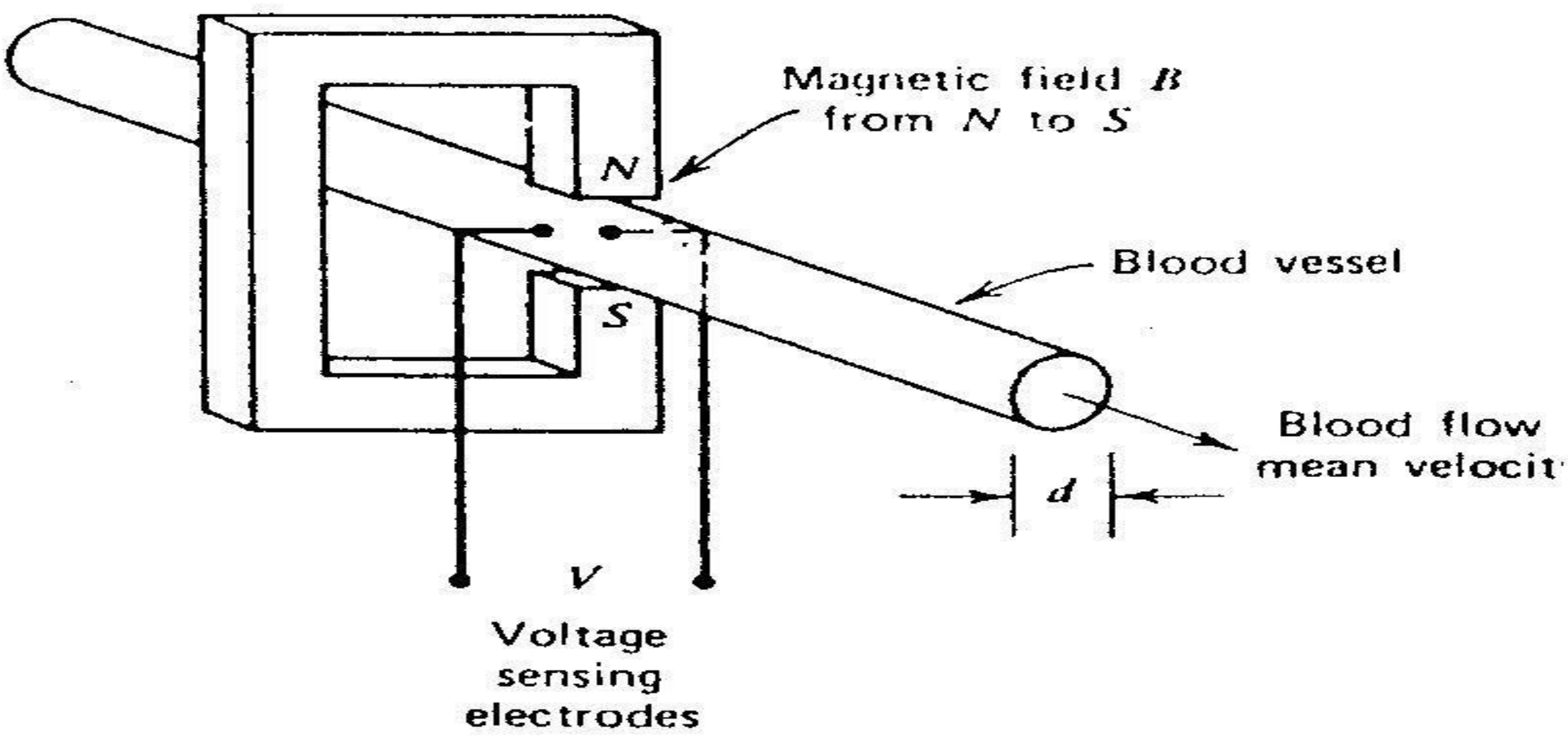
1- In short wave (30 MHz) diathermy two methods are used to get electromagnetic energy into the body: the capacitance methods and inductance method. In both methods the body part to be heated becomes a part of resonant electrical circuit.

2- In microwave (2450 MHz) diathermy.

Low-frequency electricity and magnetism in medicine

When an electrical conductor is moved perpendicular to a magnetic field, a voltage is induced in the conductor proportional to the product of the magnetic field and the voltage of the conductor (Faradays Low). This law, which also holds for a conducting fluid moving perpendicular to a magnetic field, is the basis of magnetic blood flow meters.

Blood acts as a conducting fluid. If it passes with mean voltage V through a magnetic field B as shown in (Fig.7), a voltage V is induced between the electrodes such that V =Bdv, d is diameter of vessel.



The volume of blood Q through the vessel can then be calculated.

Since Q is product of mean velocity times the area of the vessel $\pi d^2/4$. or

$$\mathbf{Q} = \frac{\boldsymbol{\pi d^2}}{\mathbf{4}}\, \boldsymbol{x}\, \frac{\mathbf{V}}{\boldsymbol{Bd}}$$

Example

A magnetic blood flow meter is positioned across blood vessel **5×10^{-3} m** in diameter. With a magnetic field **3×10^{-2} T**, and induced voltage of **15×10^{-6} V** is measured.

a. Find the mean velocity in the vessel.

$V = Bdv$, $v = V/Bd = 1.5 \times 10^{-5}/(3 \times 10^{-2})(5 \times 10^{-3}) = 0.1$ m/s.

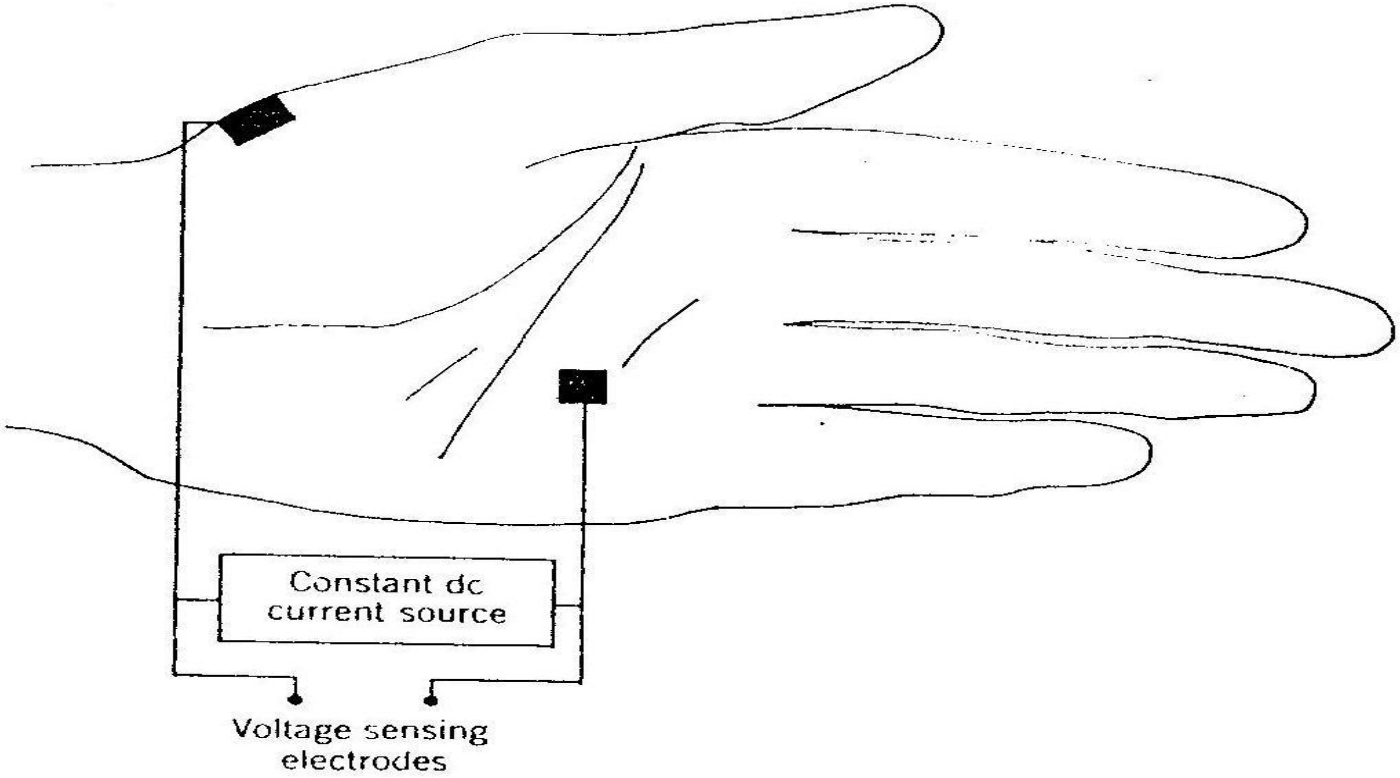
a. What is the volume flow rate.

$$\mathbf{Q} = \frac{\pi d^2}{4} x \frac{V}{Bd}$$

$Q = \pi d^2 V/4 Bd = \pi (1.5 \times 10^{-3})^2 \, 0.1 / 4 = 1.9 \times 10^{-6}$ m^3/s   =   1.9 cm^3 /s

Galvanic Skin Response (GSR)

Galvanic skin response (or GSR), also known as electrodermal response (EDR) or psychogalvanic reflex (PGR), is a method of measuring the electrical resistance of the skin and interpreting it as an image of activity in certain parts of the body.



Changing in perspiration (sweat gland activity) are related to skin resistance: the variation the skin resistance due to psychological changes or external stimuli is called the galvanic skin response (GSR). A decrease in skin resistance indicates increased sweat gland activity. Increase in skin resistance indicates reduced sweat gland activity. GSR measuring by two electrodes one placed on the palm of hand and other on the wrist. A constant direct current (~ 10 $\mu A/cm^2$) is passed: resulting voltage indicates the GSR proportional to resistance.